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ON THE DEVELOPMENT OF THERMONUCLEAR BOMBS

Work done by:

F. Evans
F. Hoyt
R. Landshoff
M. Mayer
L. Nordheim
R. Richtmyer
E. Teller
E. Zadick

Written by:

E. Teller

Super
Alarm Clock

WEAPON DATA

INTRODUCTION

In the summer of 1947 the possibilities for constructing thermonuclear bombs were reviewed. This was done with the purpose of arriving at a concrete program for the further investigation of thermonuclear explosions. Such further work is to lead to a more definite knowledge of the feasibility of the various kinds of thermonuclear bombs. In outlining further research, I have attempted to concentrate on objectives which the Los Alamos Laboratory can accomplish in the foreseeable future. I am, therefore, restricting the discussion to designs which seem to require the smallest number of new technical developments. Even so, the amount of work required for any thermonuclear gadget will prove to be very considerable.

So far, three types of thermonuclear bombs have been proposed and theoretically explored: the Super, the Alarm Clock and [redacted]. The first has been most fully described in reports: LA-344(1)-(6), LA-341, LA-401, LA-551 and LA-575. [redacted]

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[redacted] This is accomplished by a fission bomb. The reaction is then expected to spread rapidly. The feasibility of such an explosion is based [redacted]

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[redacted] Sizeable amounts of energy are nevertheless released [redacted]

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detonated. Thus the energy of these projected bombs could exceed the energy of the conventional fission bombs by several orders of magnitude.

The third design, [redacted], is an old and frequently discussed scheme. [redacted]

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In the first part of the following report a specific model of the Super will be described and critically reviewed.

In the second part the feasibility and minimum size of the Alarm Clock are discussed.

In the third part the effects of the Super or the Alarm Clock are described. These effects are compared with the effects of fission bombs.

In the fourth section a brief discussion of [redacted] is given. (b)(3)

In the fifth section a program of research and development is outlined with the purpose further to clarify the feasibility of thermonuclear bombs and to facilitate their eventual construction.

PART I: A DESIGN OF THE SUPER BOMB

The principles of operation and the main design features of a Super will be discussed in connection with Fig. I. This figure represents a model which was first presented in the Los Alamos conference of April, 1946. The advantages of this model correspond to the aims outlined in the introduction: a minimum of new technical developments is required and preference is given to a construction whose functioning can be predicted with relative ease. It is probable that other designs of the Super will require less of the materials which are difficult to produce.

In Fig. I a cross section of the initiating mechanism of the Super is given.

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The processes going on in the sphere D are complex and are, so far, not checked by direct experiments. There is reason, however, to trust the calculations which predict the reactions described above. [redacted] (b) Such problems can be, and in this case have been, treated exhaustively.

I believe that the energy-transmission between A and D is very likely to proceed as described. Furthermore this part of the design is sufficiently flexible to be modified if some unexpected difficulties in this energy transmission should be found. The functioning of sphere D depends on the reliability of the measurements of Deuterium-Tritium cross sections and on the correctness of calculations. Both have been carried out with care. Furthermore, conditions are not marginal and one may have thus considerable confidence that region D will function as described.

The 14 million volt neutrons generated in [redacted] tion shield F.

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The functioning of regions G and H is very hard to calculate because in these extended regions variations in time and space must both be taken into account. An attempt at such a calculation was carried out in the Spring of 1946 on the electronic computer, the so-called ENIAC. [redacted]

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In the past months a more detailed investigation of this question has been carried out. This investigation is actually the only relevant progress with regard to the Super since the beginning of 1946.* These considerations are summarized in Appendix I. [redacted] (b)(3) remain the most doubtful points in the feasibility of the Super. The calculations performed during this summer are expected to continue; checks on numerical results and on the consistency of the approximations used will have to be carried out. Further calculations will probably require high-speed electronic computing equipment. I believe, however, that at the present stage not very much doubt remains that the Super in principle is feasible.

The residual doubt is of three kinds. [redacted] (b)(3) his question has been considered now by a considerable number of men for several years and no flaw has been so far detected. Second, the propagation of the reaction in the charge requires the discussion of a non-linear partial integro-differential equation. The mathematical handling of this question is incomplete and may have to remain not quite complete up to an actual test. Work carried out during this summer and described in Appendix I diminishes, in my opinion, the reason to doubt that the thermonuclear reaction can be made to propagate. Third, the actual design of the Super is complex. It is possible that during actual construction further difficulties will arise which it is hard to foresee at the present stage of long-range planning.

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* All statements concerning calculations and proofs other than this last question can be found in the reports quoted in the introduction. Since these proofs are not new, they have not been included in the present report.

In order to give an overall picture of the Super we include the schematic Fig. II.

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In conclusion it may be stated that the Super is probably feasible. Its complex construction gives us little hope that it can be actually made to work in the next 3 or 4 years. It requires, furthermore, considerable amounts of Tritium.

PART II: THE ALARM CLOCK

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last part we shall describe an experimental method of getting information on this point. In the following I shall outline the normal working of the Alarm Clock and I shall give some qualitative arguments concerning mixing.

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On the basis of the best available information on cross sections we have estimated that the total number of fissions caused by 2½ million volt neutrons is approximately .2, and the total number of fissions due to 14 million volt neutrons is .7. In these estimates neutrons slowed down below the 28 threshold are not included because [redacted] The estimates are consistent with integral experiments in which D-D neutrons are caught in a Uranium block (Reported in LA-304) and with similiar experiments now in progress under the direction of Dr. Taschek in which D-T neutrons are used. The effect of the Deuterium could so far only be crudely estimated.

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Actually the calculations carried out in the Appendix are crude approximations. The two most important simplifications introduced are: It is assumed that at any one time [redacted]

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A complete calculation taking into account these neglected effects is likely to become feasible only when high speed computing equipment becomes available. Such complete calculations are likely to show that the real ignition

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[redacted] It should be remarked, however, that our present knowledge of cross sections is still so uncertain that a further considerable change of the required ignition energy might result. [redacted]

[redacted]

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In addition to these effects fission products and other radioactivities may spread radiation sickness over a big area.

[redacted]

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It is very hard to estimate the extent of the areas which would be affected by the radioactivities produced. The effects will depend on the methods of detonation. In fact, it is possible that most of the activity will go up to the stratosphere and will not be mixed with the troposphere until some late time at which the radioactivities have sufficiently decayed. Again if a considerable amount of dust is stirred up, the radioactive material might precipitate out of the atmosphere within a short distance, thus contaminating a relatively small area. The radioactive effects will depend not only on the mode of delivery but also on the atmospheric conditions.

As a general rule one will expect rather freakish effects, such as have been observed in connection with the Trinity explosion where some areas obtained strong activities while surrounding areas were unaffected.

In order to make an estimate, we shall assume that the radioactive products are thoroughly mixed up in the troposphere and that none of the radioactive products go up into the stratosphere or are deposited on the ground. This condition is not necessarily the most dangerous one that can arise. One might be able to find ways of loading down the activity with the right size of dust particle to prevent a rise into the upper troposphere. One might find atmospheric conditions where the dust remains suspended and thoroughly stirred in the lower parts of the troposphere.

It would be even more dangerous if the winds would deposit the radioactivity products more or less uniformly along their path, because in this way the effects of the activity instead of being spread out throughout the whole troposphere will be concentrated to the lower hundred meters of atmosphere, thus multiplying the effectiveness by about a factor of 100. Furthermore, the freakish nature of the distribution of activities in the atmosphere is apt to endanger much bigger territories than will actually be destroyed. Concentration of the activities into the lower troposphere or proper conditions of settling may, however, be hard to obtain. We shall, therefore, restrict our discussion to uniform distribution of the products throughout the troposphere and we may consider the results of this calculation as an upper bound to the radioactive danger that can be produced in a relatively easy and straightforward manner.

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The number of delayed gamma rays of approximately a million volt energy emitted during the time dt at time t after explosion is given by $0.1\ N\frac{dt}{t}$ where N is the number of fissions that had occurred. Each of those gamma rays is capable of producing 30 thousand ion pairs and 2×10^9 ion pairs per cubic centimeter of air is the equivalent of 1 R unit. Setting the dangerous dose of irradiation equal to 400 R units, one finds that [redacted] can contaminate (b)(3 a thousand cubic miles of air. Setting the effective thickness of the troposphere equal to 6 miles, we find that the radioactive contamination will extend over 160 square miles. This area is somewhat smaller than the area strongly damaged by shock and radiation. One must remember, however, that the area just mentioned will not overlap the area damaged by the other methods but will rather extend down-wind from the point of explosion.

If a Super is used instead of the Alarm Clock and if no special arrangements are made to utilize the radioactivity of the fission products, the radioactive damage will be insignificant in comparison with other damage done. If, however, special arrangements are made to utilize the neutrons in making fission products or other radioactive materials, one gets effects similar to those in the case of the Alarm Clock. In fact, by absorbing the neutrons in appropriate materials and generating activities of the right kind of lifetime, one might obtain from the Super many times the radioactive effect produced by an Alarm Clock.

It is in the nature of the Super and the Alarm Clock that the energy released by either of these objects may be increased with hardly any practical limit. As a practical example, I shall discuss here the structure and effects of a Super or an Alarm Clock producing energy in the neighborhood of

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There seems to be, however, no reason to believe that such a great engineering development cannot be accomplished within a few years. It is also clear that delivery of such an object by aircraft is likely to remain impossible for quite some time to come. We shall see, however, that delivery by boat or submarine is capable of producing disastrous effects. The

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[redacted] (b)(3)

This again is an object that one hardly will be able to transport by air. We have seen that perhaps the most hopeful design for an Alarm Clock [redacted] (b)(3)

This would decrease the engineering difficulties. It seems to me that if an Alarm Clock can be made at all, a big scale Alarm Clock could be more easily engineered than a big scale Super. Even so, the engineering and transportation of a one-billion-ton Alarm Clock will remain quite difficult.

It is uncertain that the main damage done by a billion-ton explosion will be either through shock or through flash burns. I expect that shock damage by very big explosions will be limited by the depth of the atmosphere. A bomb which is capable of developing one atmosphere over-pressure at a distance of 6 miles is likely to blow out a part of the atmosphere. If the size of the bomb is further increased, the result may easily be that one will blow out a part of the atmosphere with somewhat greater violence but one will not accomplish a much greater sidewise extension of the shock damage. It seems to me likely that it will be difficult to destroy an area greater than approximately one thousand square miles by shock.

The effects of flash burn would continue to increase with the square root of the energy, provided that the bomb is detonated sufficiently high above ground. Thus, a billion-ton explosion could cause very serious flash burns at a distance of 100 miles, and an area of 30 thousand square miles would be affected. This, however, would require that one detonates the bomb a little higher than one mile above ground. Otherwise, the horizon of the bomb would be too small.

As long as such big bombs can not be carried in aircraft or rockets, flash burn is not likely to determine the size of the damaged area.

The upper limit of radioactive damage, estimated in the same way as it has been estimated for the smaller Super and Alarm Clock, will now be greater by a factor 100, since the number of neutrons and fissions produced are greater by this factor. Thus, an area of 16 thousand square miles might be affected. Furthermore, by appropriate choice of meteorological conditions, this area might be made to cover a rather elongated territory in the down-wind direction from the detonation point. It may, for instance, actually cover a strip 40 miles broad and 400 miles long. In order to give a frightening, although improbable, example of what these effects might amount to, let us consider a bomb of this type dropped near Washington, D.C. Let us assume that the winds are blowing north along the Alleghanies, a condition quite frequently encountered. Then Washington, Philadelphia, New York and Boston could all be close to the path of the radioactive cloud and even the farthest point, Boston, would be within reach of the danger.

This example by itself shows that the Super or Alarm Clock may be much more dangerous even than great numbers of fission bombs. The destruction of Washington, Baltimore, Philadelphia, New York and Boston would probably require more than 100 atomic bombs. Furthermore, the damage due to the Super or Alarm Clock will extend over the highly industrialized countryside as well as over the cities themselves. The wholesale destruction of the general neighborhood would impede any rescue or reconstruction and finally defense against a single object might be more difficult than defense against a considerable number of fission bombs.

It will be clear that the damage which can be inflicted by a Super or Alarm Clock is rather different from the damage which can be done by fission bombs. The greatest single difference is that the Super or Alarm Clock can cause more concentrated destruction, while more wide-spread damage can be done by fission bombs. For this reason, I believe that from the military point of view, the Super or the Alarm Clock will not actually make the fission bomb obsolete. It will, however, give rise to new types of effects which can be matched with the help of fission bombs, only at a probably much greater cost. This is all the more true because of the fact that the expense in the case of the Super and the Alarm Clock will essentially go into research and development, while a much greater fraction of the expense in the case of fission bombs has to go into more straightforward industrial production. Thus, the efforts along these two lines are not mutually exclusive because they involve to a considerable extent different personnel and different facilities.

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in Hanford are made available for Tritium production.

[redacted]

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PART V. PROGRAM OF RESEARCH AND DEVELOPMENT:

Experiments which are now under way in Los Alamos will greatly help to clarify [redacted]. The most important pieces of information which at present are quite incomplete and need further study are: the elastic, the inelastic and particularly the fission cross sections of high energy neutrons up to 14 Mev in ordinary Uranium. The same information for 25 and 49 and possibly 23 would be also of interest, though to a considerably lesser extent. It would be, however, of quite basic importance to study for high energy neutrons the elastic cross section of Deuterium and also the cross section for the disintegration of Deuterium into a proton and a neutron. There is some interest in studying the neutron cross sections in the high energy range for beryllium, oxygen and aluminum;

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Further research of D+D and D+T cross sections continues to be of interest. While these cross sections have been measured carefully, it is not yet quite clear that their values are more accurate than 20 or 30% even in the

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In order to evaluate the cross sections for the lower energies, it would be of interest to study the ranges of Tritium and Deuterium at low energies. These ranges cannot be calculated with sufficient reliability because we are considering here nuclei which move with velocities similar to that of the electrons in their outermost orbits. Under such conditions theoretical range calculations become extremely tricky and ranges may even depend on chemical composition. This piece of research, in particular as it relates to the range of Deuterium, could possibly be farmed out.

It is of some interest to explore some of the reactions which might become significant in advanced stages of the reactions of the Alarm Clock or the Super.

I refer in particular to further research on the reaction of He^3 + D and also to the T+T reaction. These problems, however, are of considerably less importance than those mentioned above, since they will help to determine the exact energy output of the Super or the Alarm Clock rather than their feasibility.

Fully as important as the most vitally needed differential cross sections are integral experiments. Some of these have already been performed, such as the number of fissions produced in a big mass of Uranium by DD and by DT neutrons. These experiments should be repeated, [redacted] (b)(3) For the time being, such experiments will probably have to be carried out using heavy water, since [redacted] or other substances of the composition [redacted] are not at present (b)(3) available in sufficiently large quantities. It would be of great importance to explore the possibilities of obtaining such substances in amounts of approximately [redacted]. This again is a problem that might be farmed out. (b)(3)

Further laboratory research should be performed in preparation of tests which in turn will be of importance in determining the feasibility of the Alarm Clock. I refer in particular to the exploration of the fission spectrum in the neighborhood of and above 14 Mev. As will be mentioned further below, tests on the feasibility of the Alarm Clock may be carried out in connection with Trinity-type explosions. The success of these testing procedures with regard to the feasibility of the Alarm Clock, however, depends on producing enough 14 Mev neutrons from a D+T reaction, so that these neutrons should be clearly distinguished above the background of the fission neutrons. It will, therefore, be necessary to develop methods to detect these high energy neutrons. This is best done by developing an appropriate threshold detector. Furthermore, it will be necessary to study the fission spectrum near and above 14 Mev. The fast reactor at Los Alamos is a machine particularly adapted to this study.

The experiments outlined above can be carried out at Los Alamos without interfering with that part of the work of the Laboratory which for short range purposes is most important. In particular, one can hope that the most important pieces of valuable information--namely, fission cross sections and n-D cross sections in the high neutron range, the integral experiments, the threshold studies, and the analysis of the fission spectrum in the high energy range-- may be carried out within a year. It would be of particular interest to make fast progress with the two topics last mentioned, since the forthcoming Pacific tests could give us already next Spring interesting pieces of information, if appropriate threshold detectors were available and if we should know enough about the shape of the fission spectrum in the high energy range. If such measurements could be carried out during the coming Spring in the Pacific, the results could be used as valuable points of comparison to which results of later tests could be referred.

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[redacted] Those latter reactions produce 14 Mev neutrons which can be distinguished by threshold detectors from the background of fission neutrons produced in the bomb. It is likely that the layer thickness of [redacted] mentioned above will be sufficient to produce (b)(3) enough of these 14 Mev neutrons to be clearly distinguishable from the high energy tail of the fission spectrum. This last statement, however, is at the present time subject to doubt because our present knowledge of the high energy tail of the fission spectrum is quite incomplete. If the 14 Mev neutrons should not be produced [redacted] in the expected amount, [redacted] (b)(3) radius or less would cause an essential diminution of the rate of the D+T reaction, as explained in Part III. It should, of course, be kept in mind that this experiment requires, among other things, a sufficiently reliable prediction of the number of D+T neutrons to be expected and this in turn will become possible only when calculations give us a rather complete description of the temperature-and pressure-distribution within an exploding bomb.

[redacted]

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I should like to propose that the two tests described above should be carried out as soon after the Pacific tests of next Spring as is feasible. With the help of these tests, we could form a judgment in 18 or 24 months from now whether the Alarm Clock is feasible or not. In the meantime the experimental program described in the first portion of Part 5 of this report should have furnished us with enough information to make a more close estimate of the energy needed to ignite the Alarm Clock. At approximately the same time, high speed computational facilities are likely to become available so that we shall be in a much better position to solve the integro-differential equations which occur in the theory of the Alarm Clock. Thus, we are likely to be able to form at that time a realistic estimate of the work involved in making an Alarm Clock. I think that the decision whether considerable effort is to be put on the development of the Alarm Clock or the Super should be postponed for approximately 2 years; namely, until such time as these experiments, tests, and calculations have been carried out.

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In view of our present uncertainty about the radiation damage that a Super or Alarm Clock could cause, there seems to be increased justification in making close meteorological study of the fate of the fission products in all tests to be carried out. In themselves such studies will not allow us to predict the behavior of the fission products in the Super or Alarm Clock. The greater energy developed in these later bombs might invariably cause a lifting of the fission products into the stratosphere. On the other hand, if the detonation is performed near the ground or sea level, the dust or water thrown up may be of such mass as to modify the distribution of the fission products quite thoroughly. However, the forthcoming tests are the closest approach to the problem that we shall have for some time.

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Calculations on the Super, Alarm Clock [redacted] bomb may be continued (b)(3) with considerable profit. Eventual use of fast computing equipment may be speeded if the theory of these bombs is not neglected in the near future.

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We have made an attempt to find a solution for the propagation which is stationary and stable in the same sense as these words are used in the theory of detonations in high explosives. It is, of course, not clear in principle that such a solution exists at all nor is it at all clear that a solution will be stable against all perturbations and whether it will be rapidly approached whenever the ignition has been successful. These questions are among the most difficult ones of hydrodynamics and even for ordinary high explosives, they have not been completely solved.

We have calculated a number of cases. In each of these, several of the relevant effects have been neglected so as to obtain a problem sufficiently simple to be treated analytically or by simple numerical methods. These several calculations certainly do not solve the problem of the propagation of the explosion in Deuterium but by their help, we can form a better judgment as to the actual existence of a stable and steady solution. More refined calculations, taking into account effects now believed to be of secondary importance, will be undertaken in the immediate future by the use of ordinary computational methods. A still more exhaustive treatment will require the use of high-speed computing machines.

In all cases we shall neglect to discuss the dependence of the detailed temperature and pressure distributions as a function of the distance of the points from th[redacted] We shall replace the problem by a one- (b)(3)

APPENDIX II

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3. The hydrodynamic motion and the distribution of material velocities and densities inside the heated region are the same as given in Report LA-636. The velocity of the boundary of the heated region is also as obtained in LA-636. In

[redacted]

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[redacted] (b)(3)

The results of calculations are shown in Figures "a" to "f", Appendix II. In Figure "a", the temperature of the heated region is plotted against the radius of the heated region for models one and three. The time at which each temperature is attained is indicated along the curves. [redacted] (b)(3)

Figure "b", Appendix II, contains similar information on models four and five.

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Figure "c" shows cases two and six. In spite of the fact that in six an [redacted] was used the reaction still (b)(3) [redacted] . On the other hand, the reaction in case two [redacted] (b)(3)

In Figures "d", "e", and "f", Appendix II, the energy produced up to the time that a certain radius is reached by the heated region is plotted against the radius. The energy values are divided by the original energy delivered by the igniting bomb. In Figure "d", models one and three are represented. In Figure "e", the results for models four and five are shown, and in Figure "f", the values for models two and six are plotted. It is of interest to notice that in the implosion model four there [redacted] (b)(3) however, a rather formidable implosion apparatus. The energy needed to set off an Alarm Clock [redacted] (b)(3) For reasons given earlier in this Appendix, it seems that this energy is actually an overestimate.

PAGES 54 through 72 which are drawings and graphs
are withheld in their entirety pursuant to (b)(3)